AFRL-AFOSR-VA-TR-2016-0013

Designing Microstructures/Structures for Desired Functional Material and Local Fields

Liping Liu
RUTGERS THE STATE UNIVERSITY OF NEW JERSEY

12/02/2015
Final Report

Air Force Research Laboratory
AF Office Of Scientific Research (AFOSR)/ RTB2
Arlington, Virginia 22203
Air Force Materiel Command

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
01-09-2015	final	01-07-2012 - 31-07-2015

4. TITLE AND SUBTITLE
Designing Microstructures/Structures for Desired Functional Material and Local Fields

5a. CONTRACT NUMBER

5b. GRANT NUMBER
FA9550-12-1-0349

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Liping Liu

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Rutgers University
110 Frelinghuysen Rd.,
Piscataway, NJ 08854-8019

8. PERFORMING ORGANIZATION REPORT NUMBER
Final

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Office of Scientific Research (AFOSR)
875 N. Randolph Str.
Arlington VA 22203 - USA

10. SPONSOR/MONITOR'S ACRONYM(S)
AFOSR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The investigations have focused on the predictive modeling and optimal design of multifunctional materials/structures as proposed. Along the line of predictive modeling, the PI, supported students and collaborators have (i) established an atomistic model for surface elasticity, (ii) derived a new type of Maxwell stress in soft materials due to quantum mechanical-elasticity coupling and elucidated its ramification in engineering multifunctional soft materials, and (iii) demonstrated the possibility of concurrent magnetoelectricity and piezoelectricity in soft materials.
Concerning local field in heterogeneous structures, we have shown designs of thermoelectric composites and the feasibility of large-scale power plants based on thermoelectric effects. we achieve designs of structures that can amplify static electric/magnetic fields or temperature gradient. These designs can be used to improve sensitivity of telecommunication receivers and efficiency of heat engines / thermoelectric generators. We also show optimal geometries of minimum field concentration that may be used to mitigate fatigue damage and improve reliability and life-span of structures.

15. SUBJECT TERMS
Multifunctional materials, Predictive modeling, Optimal design

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(Include area code)*

Reset

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18
Adobe Professional 7.0

INSTRUCTIONS FOR COMPLETING SF 298

1. REPORT DATE. Full publication date, including day, month, if available. Must cite at least the year and be Year 2000 compliant, e.g. 30-06-1998; xx-06-1998; xx-xx-1998.

2. REPORT TYPE. State the type of report, such as final, technical, interim, memorandum, master's thesis, progress, quarterly, research, special, group study, etc.

3. DATES COVERED. Indicate the time during which the work was performed and the report was written, e.g., Jun 1997 - Jun 1998; 1-10 Jun 1996; May - Nov 1998; Nov 1998.

4. TITLE. Enter title and subtitle with volume number and part number, if applicable. On classified documents, enter the title classification in parentheses.

5a. CONTRACT NUMBER. Enter all contract numbers as they appear in the report, e.g. F33615-86-C-5169.

5b. GRANT NUMBER. Enter all grant numbers as they appear in the report, e.g. AFOSR-82-1234.

5c. PROGRAM ELEMENT NUMBER. Enter all program element numbers as they appear in the report, e.g. 61101A.

5d. PROJECT NUMBER. Enter all project numbers as they appear in the report, e.g. 1F665702D1257; ILIR.

5e. TASK NUMBER. Enter all task numbers as they appear in the report, e.g. 05; RF0330201; T4112.

5f. WORK UNIT NUMBER. Enter all work unit numbers as they appear in the report, e.g. 001; AFAPL30480105.

6. AUTHOR(S). Enter name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. The form of entry is the last name, first name, middle initial, and additional qualifiers separated by commas, e.g. Smith, Richard, J, Jr.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES). Self-explanatory.

8. PERFORMING ORGANIZATION REPORT NUMBER. Enter all unique alphanumeric report numbers assigned by the performing organization, e.g. BRL-1234; AFWL-TR-85-4017-Vol-21-PT-2.

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES). Enter the name and address of the organization(s) financially responsible for and monitoring the work.

10. SPONSOR/MONITOR'S ACRONYM(S). Enter, if available, e.g. BRL, ARDEC, NADC.

11. SPONSOR/MONITOR'S REPORT NUMBER(S). Enter report number as assigned by the sponsoring/ monitoring agency, if available, e.g. BRL-TR-829; -215.

12. DISTRIBUTION/AVAILABILITY STATEMENT. Use agency-mandated availability statements to indicate the public availability or distribution limitations of the report. If additional limitations/ restrictions or special markings are indicated, follow agency authorization procedures, e.g. RD/FRD, PROPIN, ITAR, etc. Include copyright information.

13. SUPPLEMENTARY NOTES. Enter information not included elsewhere such as: prepared in cooperation with; translation of; report supersedes; old edition number, etc.

14. ABSTRACT. A brief (approximately 200 words) factual summary of the most significant information.

15. SUBJECT TERMS. Key words or phrases identifying major concepts in the report.

16. SECURITY CLASSIFICATION. Enter security classification in accordance with security classification regulations, e.g. U, C, S, etc. If this form contains classified information, stamp classification level on the top and bottom of this page.

17. LIMITATION OF ABSTRACT. This block must be completed to assign a distribution limitation to the abstract. Enter UU (Unclassified Unlimited) or SAR (Same as Report). An entry in this block is necessary if the abstract is to be limited.

To: technicalreports@afosr.af.mil

Subject: Final Project Report to Dr. Byung L. Lee

Contract/Grant Title: (YIP 12) - Designing Microstructures/Structures For Desired Functional Material And Local Fields

Contract/Grant # FA9550-12-1-0349

Reporting Period: 1 July, 2012 to 31 July 2014

Project accomplishments: The investigations have focused on the predictive modeling and optimal design of multifunctional materials/structures as proposed.

Along the line of predictive modeling, the PI, supported students and collaborators have (i) established an atomistic model for surface elasticity [3], (ii) derived a new type of Maxwell stress in soft materials due to quantum mechanical-elasticity coupling and elucidated its ramification in engineering multifunctional soft materials [1,2], and (iii) demonstrated the possibility of concurrent magnetoelectricity and piezoelectricity in soft materials [6].

Concerning local field in heterogeneous structures, we have shown designs of thermoelectric composites and the feasibility of large-scale power plants based on thermoelectric effects [4, 5]. We achieve designs of structures that can amplify static electric/magnetic fields or temperature gradient. These designs can be used to improve sensitivity of telecommunication receivers and efficiency of heat engines / thermoelectric generators. We also show optimal geometries of minimum field concentration that may be used to mitigate fatigue damage and improve reliability and life-span of structures.

Archival publications derived from the project:

1. X.B. Li, L.P. Liu and P. Sharma. A New Type of Maxwell Stress in Soft Materials due to Quantum Mechanical-Elasticity Coupling, *J. Mech. Phys. Solids*, In review.
2. X.B. Li, L.P. Liu and P. Sharma. Geometrically nonlinear deformation and the emergent behavior of polarons in soft matter (6pg, Communication). *Soft Matter*, In press.
3. L.X. Hu and L. P. *Liu. From atomistics to continuum: effects of a free surface and determination of surface elasticity properties (10pg). Mechanics of Materials, 90, 202-211, 2015.*
4. F. Ahmadpoor, L. P. Liu and P. Sharma. Thermal fluctuations and the minimum electrical field that can be detected by a biological membrane (13 pg). *J. Mech. Phys. Solid*, 78，110-122，2015.
5. L. *P. Liu.* Feasibility of Large-scale power plants based on thermoelectric effects. *New Journal of Physics, 16, 123019, 2014.*

6. Z. Alameh, Q. Deng, L. P. Liu and P. Sharma. Using electrets to design concurrent magnetoelectricity and piezoelectricity in soft materials. *Journal of Material Research*, 30:93-100, 2015

Principle Investigators:

Liping Liu Department of Mathematics and Department of Mechanical & Aerospace Engineering, Rutgers University

Contributors to the Project:

Hanxiong Wang and Lixin Hu(supported Ph.D. students)

Project highlights:

[1] Accomplish a systematic continuum theory for multifunctional materials that can be used for predictive modeling of magneto-electro-elastic materials of any geometry and boundary conditions.
[2] Discover and elucidate a universal mechanism, i.e., the Maxwell stress, that can be utilized to engineer multifunctional soft materials for multi-sensing, multi-actuating, human-machine interfaces.
[3] Establish a theoretical framework and numerical tools for designing structures/materials with desired functionality and local fields.

Planned Continuing Work: Future work will focus on multifunctional soft materials for their unique multifunctionality and biocompatibility. The strength of the PI lies in rigorous continuum-mechanics and multiscale approach to the predictive modeling of multifunctional materials. In particular, the PI will explore the microscopic statistical mechanics models of typical soft materials and means to improve their functional properties, establish a self-consistent continuum theory for electro-magnetic-elastic materials, derive the asymptotic theories of soft composites, curved rods and membranes, and optimize a specified functionality via numerical and analytical efforts.

1.

1. Report Type

Final Report

Primary Contact E-mail
Contact email if there is a problem with the report.

liu.liping@rutgers.edu

Primary Contact Phone Number
Contact phone number if there is a problem with the report

8484457969

Organization / Institution name

Rutgers University

Grant/Contract Title
The full title of the funded effort.

Designing Microstructures/Structures for Desired Functional Material and Local Fields

Grant/Contract Number
AFOSR assigned control number. It must begin with "FA9550" or "F49620" or "FA2386".

FA9550-12-1-0349

Principal Investigator Name
The full name of the principal investigator on the grant or contract.

Liping Liu

Program Manager
The AFOSR Program Manager currently assigned to the award

Byung Les Lee

Reporting Period Start Date

07/01/2012

Reporting Period End Date

07/01/2015

Abstract

The investigations have focused on the predictive modeling and optimal design of multifunctional materials/structures as proposed.

Along the line of predictive modeling, the PI, supported students and collaborators have (i) established an atomistic model for surface elasticity, (ii) derived a new type of Maxwell stress in soft materials due to quantum mechanical-elasticity coupling and elucidated its ramification in engineering multifunctional soft materials, and (iii) demonstrated the possibility of concurrent magnetoelectricity and piezoelectricity in soft materials.

Concerning local field in heterogeneous structures, we have shown designs of thermoelectric composites and the feasibility of large-scale power plants based on thermoelectric effects. we achieve designs of structures that can amplify static electric/magnetic fields or temperature gradient. These designs can be used to improve sensitivity of telecommunication receivers and efficiency of heat engines / thermoelectric generators. We also show optimal geometries of minimum field concentration that may be used to mitigate fatigue damage and improve reliability and life-span of structures.

Distribution Statement

This is block 12 on the SF298 form.

Distribution A - Approved for Public Release

Explanation for Distribution Statement

If this is not approved for public release, please provide a short explanation. E.g., contains proprietary information.

SF298 Form

Please attach your SF298 form. A blank SF298 can be found here. Please do not password protect or secure the PDF The maximum file size for an SF298 is 50MB.

finalreport-form298.pdf

Upload the Report Document. File must be a PDF. Please do not password protect or secure the PDF . The maximum file size for the Report Document is 50MB.

FinalReport-YIP12-LipingLiu-2015.pdf

Upload a Report Document, if any. The maximum file size for the Report Document is 50MB.

Archival Publications (published) during reporting period:

Changes in research objectives (if any):

Change in AFOSR Program Manager, if any:

Extensions granted or milestones slipped, if any:

AFOSR LRIR Number

LRIR Title

Reporting Period

Laboratory Task Manager

Program Officer

Research Objectives

Technical Summary

Funding Summary by Cost Category (by FY, $K)

	Starting FY	FY+1	FY+2
Salary			
Equipment/Facilities			
Supplies			
Total			

Report Document

Report Document - Text Analysis

Report Document - Text Analysis

Appendix Documents

2. Thank You

E-mail user

Nov 13, 2015 12:48:46 Success: Email Sent to: liu.liping@rutgers.edu